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Observed and projected shifts in hot extremes' season in the Eastern Mediterranean

Founda D.*, Varotsos K.V., Pierros F., Giannakopoulos C.

Institute for Environmental Research & Sustainable Development, National Observatory of Athens, I. Metaxa & V. Pavlou, P. Penteli, Athens GR-15236, Greece

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ABSTRACT

In the background of global warming, the Mediterranean area has been recognized as a hot spot with respect to observed and projected heat related risk, manifested mainly through increased frequency and severity of hot extremes. This study explores changes in the timing and seasonality of different hot extreme indices, using historical air temperature data at a number of stations at the Eastern Mediterranean. In addition, daily output from several Regional Climate Models realisations is analyzed to estimate future seasonal shifts under climate change. The analysis of observational data reveals significant changes in the seasonality of hot extremes and specifically lengthening of their period, which in some cases exceeds 10 days per decade, attributed to earlier rather than later occurrence. Shifts in the timing of hot extremes related to nighttime (daily minimum) temperature are larger and more robust among different stations compared to daytime extremes. Future simulations indicate further lengthening of the hot extremes' season by approximately one month in the near future (2021–2050) and by more than two months in the distant future (2071–2100) with respect to the control period (1971–2000). Such significant changes are expected to have a profound environmental, economical and societal impact in the area.

1. Introduction

Climate change emerges as one of the most serious threats for our planet and has moved to the frontline of global agenda during the last years. Today, there is strong scientific consensus that, man-made forcing related to increased anthropogenic emissions and changes in land use has contributed to unprecedented global warming (IPCC, 2014). In addition to observed changes in the mean climate, recent studies provide evidence of increased frequency of extreme weather events, such as hot extremes (Fischer and Knutti, 2015).

While extremely hot episodes are part of the natural climate variability, the severity and frequency of such episodes has been found to increase in the background of climate change and long term warming (Alexander et al., 2006; Perkins et al., 2012; Meehl et al., 2007; Stott et al., 2016). In particular, Fischer and Knutti (2015) estimated that today, about 75% of the moderate daily hot extremes over land (defined as events expected to occur 1 in every 1000 days under present conditions) are attributable to global warming. In some cases, the frequency of very hot days (i.e. those exceeding the 99th percentile of daily maximum temperature distribution) has more than tripled during the past century (Founda et al., 2004; Founda, 2011; Scherrer et al., 2016). Changes in the characteristics of prolonged hot episodes (heat waves) with respect to their severity or duration are also reported in most parts of the world (Della-Marta et al., 2007; Panda et al., 2014; Habeeb et al., 2015). Additionally, projections from global climate models suggest a further increase in the severity, duration and frequency of heat waves in the future (Meehl and Tebaldi, 2004; Coumou et al., 2013; Perkins-Kirkpatrick and Gibson, 2017; Guerreiro et al., 2018), but also increases in absolute record temperatures (Abatzoglou and Barbero, 2014).

Exceptionally hot weather has profound impacts on society, economy and environment. Specifically, epidemiological studies have shown that historical extreme heat events have led to particularly increased mortality or morbidity in the past (Poumadère et al., 2005; Anderson and Bell, 2011; Coumou et al., 2013), while in some countries (e.g. Australia) hot weather has been recognized as the deadliest natural hazard (https://www.pwc.com.au/industry/government/assets/extreme-heat-events-nov11.pdf). Furthermore, heat events and concurrent droughts have triggered catastrophic wildfires in many parts of the world (Founda and Giannakopoulos, 2009).

In addition to changes in the frequency and intensity of several climatic indices, changes in the timing of their occurrence and consequent seasonal shifts have also received special attention by scientists recently. Based on phenology and/or climatic data, seasonal shifts have

* Corresponding author.
E-mail address: founda@noa.gr (D. Founda).

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been reported in different regions, with earlier spring and consequent winter shrinkage being the most common finding (e.g. Sparks and Menzel, 2002; Schwartz et al., 2006; Christidis et al., 2007; Post et al., 2018). Schwartz et al. (2006) found an earlier onset of spring (ranging from 1 to 1.5 days/decade) across most temperate Northern Hemisphere (NH) land regions over the 1955–2002 time period. Similarly, Christidis et al. (2007) found a significant increase in the growing season length by ~1.5 days/decade over Europe and North America during the period 1950–1999, as a result of earlier spring rather than later winter onset, attributable to global warming. Based on phenological observations, Post et al. (2018) found an earlier onset of springtime at NH by approximately 0.4 to 0.5 days/decade per increasing latitude degree, consistent with the acceleration of warming with latitude. Shifts in the phase of the annual cycle of surface temperature over extratropical land are also reported by Stine et al. (2009). The authors found that the hottest day of the year comes 1.7 days earlier from the mid-1950s onward, compared to the period 1850–1950. Habeeb et al. (2015) found significant changes in the timing of heat waves (HWs) in large USA cities from 1961 to 2010 and estimated an average expansion of the HWs season by 6 days/decade.

The advancing in hot weather and the expansion of the warm period of the year is of vital importance, as it has a strong multidisciplinary impact by influencing various sectors such as the environment, human health, tourism, agriculture, and energy consumption. For instance, early occurrence of heat stress in Italy was found to have a strong impact on wheat yield (Fontana et al., 2015), while Barbero et al. (2015) reported increased projected potential of very large fires in the USA, associated with changes in the seasonality of favourable atmospheric conditions. The timing of hot temperature extremes has been found to be influential on human health, as well. Most studies suggest increased thermal risk during early heat waves, mainly due to lack of acclimatization of vulnerable population (Kalkstein et al., 2008; Chen and Li, 2017). Anderson and Bell (2011) also stress the importance of timing on heat wave effects and found that first-in-season heat waves had stronger effects than later ones. Similarly, Kyselý (2004) reports increased percentage of mortality in the Czech Republic during heat waves occurring early in the summer, while Hajat et al. (2002) found that hot days occurring in the early part of the year in London had a larger impact than those occurring later on. Nevertheless, other studies report higher mortality during heat waves in mid or late summer (Tong et al., 2014; Chen et al., 2017).

Adopting the significance of changes in seasonality of hot extremes with respect to inherent multidiscipline implications, the present study aims to explore the long-term variability and trends in timing, namely the date of first and last occurrence of several hot extreme indices, and subsequently the variations in their season's length, focusing on a climatically sensitive area. To this end, we analyse air temperature time series at a number of sites in Greece and Cyprus, covering a period of several decades. The study area belongs to the Eastern Mediterranean Basin, a region that has been assigned as one of the most responsive to climate change areas in the world, mainly regarding the observed and projected occurrence of warmer and drier conditions (Diffenbaugh et al., 2007; Kuglitsch et al., 2010; Coumou and Robinson, 2013; Lelieveld et al., 2012, 2014; Perkins-Kirkpatrick and Gibson, 2017). Greece in particular, has been experiencing prominent increase in the mean air temperature and hot extremes frequency since the mid 20th century (Nastos and Matzarakis, 2008; Nastos et al., 2011), with warming rates at some areas approximating 1 °C/decade since the mid 1970s (Founda, 2011; Founda et al., 2015). Similarly, a significant warming has been reported in Cyprus since the mid 1970s, which is stronger in the daily minimum rather than the maximum air temperature (Türkeş and Sariş, 2007). Yet, capital cities of the Eastern Mediterranean like Athens and Nicosia were identified as hot spots among 571 European cities with respect to future heat related risk (Guerreiro et al., 2018).

Finally, to examine the changes induced by climate change over the area of interest, data from several Regional Climate Models realisations were analyzed to estimate future trends in the timing of extremes and their season's length under the RCP8.5 business-as-usual scenario.

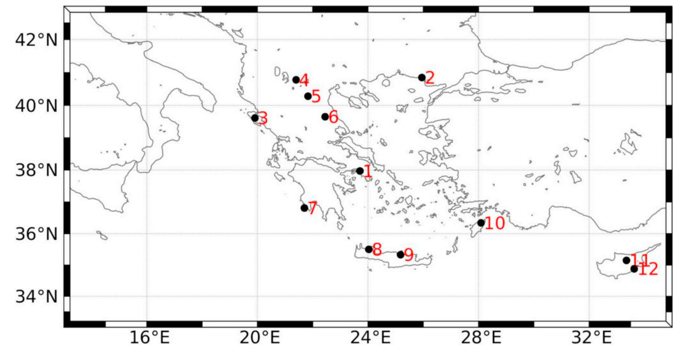

Fig. 1. Locations of the selected stations in Greece (1 − 10) and Cyprus (11 − 12). Numbering corresponds to station names as presented in Table 1.

2. Materials and methods

2.1. Study area & data

The study analyses historical surface air temperature observations at a number of sites in Greece and Cyprus, as depicted on the map of Fig. 1. Selected Greek stations (except for Athens) belong to the network of the Hellenic National Meteorological Service (https://www.hnms.gr) and stations from Cyprus belong to the Cyprus Department of Meteorology (http://www.moa.gov.cy/moa/ms/ms.nsf/DMLforecast_en/DMLforecast_en#). The selection criteria were based on the availability of long, uninterrupted time series of daily maximum and minimum temperature (T_{max}, T_{min}) without relocation of stations and on the need of a representative geographical coverage, including also sites with different characteristics (e.g. coastal, inland and urban). Moreover, the list of stations includes some of the most popular touristic destinations of the area, for instance Rhodes, Crete, Corfu, Athens and Nicosia. Possible changes in the warm season's duration are particularly influential on the touristic activity of the area. Air temperature series start from the mid 20th century or later, securing in each case a study period spanning at least four decades at all stations. Names of stations and study periods are presented in Table 1 and depicted in Fig. 1.

Air temperature data for Athens were derived from the historical archives of the National Observatory of Athens (NOA). These are the oldest climatic records for the area extending back to the late 19th century (without station relocation). The period 1896–2017 was selected for the present analysis, enabling the study of changes in the seasonality of hot extremes on centennial scale. The NOA station is located in the centre of the city, thus bears the characteristics of an urban station. The city has been experiencing marked increasing trends in air temperature over the past decades attributed to both, global and regional warming, and the well documented urban heat island (UHI) effect (Founda et al., 2015; Founda and Santamouris, 2017). Urban areas are particularly vulnerable to hot extremes due to the additive effect of the UHI phenomenon and synergistic reactions between UHIs and HWs (Founda and Santamouris, 2017). Specifically, elevated urban temperatures during HWs may increase the heat-related mortality rate in cities four times as much than in surrounding rural areas (Tan et al., 2010; Habeeb et al., 2015).

2.2. Methods

2.2.1. Hot extremes metrics

There is a plethora of climatic indices in literature concerning hot temperature extremes (e.g. Klein Tank and Konnen, 2003; Alexander

Table 1
Names and coordinates of the stations shown in Fig. 1, along with study periods and statistics of the background climate for each station. (Abbreviations 'GR' and 'CY' correspond to Greek and Cyprus stations respectively).

Station no.	Station name	Lat (°N)	Long (°E)	Study period	T_{max} (mean)* (°C)	95th percentile* (°C)	90th percentile* (°C)
1	Athens (GR)	37.97	23.71	1896–2017	32.1	36.8	35.6
2	Alexandroupolis (GR)	40.85	25.95	1955–2013	29.3	34.6	33.5
3	Corfu (GR)	39.61	19.91	1966–2013	30.2	35.2	34.0
4	Florina (GR)	40.78	21.4	1961–2013	28.1	34.6	33.0
5	Kozani (GR)	40.28	21.83	1955–2013	28.4	35.0	33.2
6	Larissa (GR)	39.65	22.45	1955–2013	32.1	37.6	36.2
7	Methoni (GR)	36.81	21.71	1956–2013	27.3	31.4	30.2
8	Souda (GR)	35.50	24.03	1959–2013	29.9	35.6	34.0
9	Iraklio (GR)	35.33	25.18	1955–2013	27.9	32.6	31.0
10	Rhodes (GR)	36.34	28.09	1973–2013	29.0	33.0	32.0
11	Nicosia (CY)	35.15	33.35	1950–2017	35.8	40.3	39.4
12	Larnaca (CY)	34.88	33.63	1976–2017	31.7	35.5	34.6

* The values refer to the summer T_{max} of the reference period 1971–2000.

et al., 2006; Zhang et al., 2011). These are absolute extreme indices (e.g. the warmest/coldest day or night of the year), indices based on predefined threshold values, or indices based on percentiles accounting for the local climate at the study area. These indices are used selectively, depending on the kind and aim of the study, as for instance impact assessment or climatic study.

In order to evaluate changes and trends in the timing of hot extremes in the area of interest we have used a combination of different types of hot extreme indices, based either on predefined temperature thresholds or on local climate statistics. First, time series of the daily maximum (T_{max}) and daily minimum (T_{min}) air temperature were created for the entire available period of observations for each station.

The main indices selected for the study are summarized in Table 2. The threshold values set for the hot extreme indices (tropical nights, warm or tropical days and hot days) are in line with indices proposed by ETCCDI (Team on Climate Change Detection and Indices) (http://etccdi.pacificclimate.org) but are also broadly used in literature (e.g. Collins et al., 2000; Hajat et al., 2002; Nastos and Matzarakis, 2008; Fischer and Schär, 2010; Panda et al., 2014). The selected indices are realistic for the analysis as they fit to the background climate of the study area (Table 1), while they are consistent with population's perception for warm or hot weather.

Two additional fixed indices were used to represent 'very hot' days and 'hot' nights, when $T_{max} > 37\,°C$ and $T_{min} > 26\,°C$ respectively. The threshold value of 37 °C approximates the 99th percentile of the annual T_{max} distribution (or the 95th percentile of the summer T_{max} distribution) in Athens for the period 1971–2000 (Founda et al., 2015), while the threshold value of 26 °C corresponds to the 99th percentile of the annual T_{min} distribution (or the 95th percentile of the summer T_{min} distribution). The indices are mainly applied at the urban areas of Athens and Nicosia to further highlight trends and increased thermal risk at large Mediterranean cities.

Once the hot extreme indices were determined, the number of days from January 1st until the occurrence of the first and the last hot extreme was calculated for each year. The extremes' season was then defined as the time interval (number of days) between the date (calculated as the Julian Day, JD) of the first and last extreme as follows:

$$Extreme's\ Season\ (days) = JD\ (Last\ Extreme) - JD\ (First\ Extreme) + 1.$$

A linear regression analysis was applied to estimate long-term trends in timing and length of hot extremes' seasons. Statistical significance of the results was examined through the Student's *t*-test.

2.2.2. Future simulations

We employed daily maximum and daily minimum temperature data for the closest land grid point to the meteorological station's location from three transient realisations of the Regional Climate Model RCA4 of the Swedish Meteorological and Hydrological Institute (SMHI, Strandberg et al. (2014) and references therein) driven by three different Global Climate Models (GCM). This makes the combined modeling system substantially diverse so as to be considered as different models. The driving GCMs are the CNRM-CM5 (Voldoire et al., 2012) (hereafter referred to as CNRM-RCA4), the Hadley Centre Global Environmental Model version 2 Earth System, HadGEM-ES (HadGEM) (Collins et al., 2011) of the Met Office Hadley Centre (MOHC), (hereafter referred to as MOHC-RCA4) and the Max Planck Institute for Meteorology model MPI-ESM-LR (Popke et al., 2013), (hereafter referred to as MPI-RCA4). The horizontal resolution of the RCA4 model is 0.11° (~12 × 12 km), and the simulations were carried out in the framework of the EURO-CORDEX modeling experiment (http://www.euro-cordex.net). The simulated data cover the period 1970–2100. The RCP8.5 future emissions scenario (Riahi et al., 2011) is implanted in the simulations after 2005 covering the period 2006–2100. We analyzed both the trend of the whole data series for the various indices,

Table 2
Selected indices for hot extremes along with abbreviations and definitions.

Index	Abbreviation	Definition
Tropical night(s)	TN(s)	Nights when daily minimum temperature, $T_{min} > 20\,°C$
Tropical day(s)	TD(s)	Days when daily maximum temperature, $T_{max} > 30\,°C$
Hot day(s)	HD(s)	Days when daily maximum temperature, $T_{max} > 35\,°C$
First tropical night	First TN	Julian Day (JD) of the first TN occurrence
First tropical day	First TD	Julian Day (JD) of the first TD occurrence
First hot day	First HD	Julian Day (JD) of the first HD occurrence
Last tropical night	Last TN	Julian Day (JD) of the last TN occurrence
Last tropical day	Last TD	Julian Day (JD) of the last TD occurrence
Last hot day	Last HD	Julian Day (JD) of the last HD occurrence
Season of tropical nights	STN	JD (Last TN) – JD (First TN) +1
Season of tropical days	STD	JD (Last TD) – JD (First TD) +1
Season of hot days	SHD	JD (Last HD) – JD (First HD) +1

as well as the changes between two future periods (2021–2050 and 2071–2100) against 1971–2000, which was used as the reference period. The 1971–2000 period was also used to evaluate the model against the observations.

Regarding the models' performance against the observations, the analysis (not shown) revealed both cold and warm biases for the annual cycle of the mean monthly maximum and minimum temperatures, depending on the station. Therefore, we opted to perform bias adjustment to the model output using the unbiasing method (Déqué, 2007). More specifically, to implement the bias adjustment initially we calculated the mean monthly differences for the 30-yr period (1971–2000) between the observations and the simulations for both the maximum and the minimum temperatures for each station. Consequently, to obtain the bias adjusted model daily data, the mean monthly differences were added to the daily simulated values. This method maintains the absolute trend as well as the variability of the simulated data at all time scales (Hempel et al., 2013).

3. Results

3.1. Observed trends in the timing of hot extremes

Fig. 2 presents the trends (estimated slopes from the linear regression analysis) in the dates (JD) of the first and last occurrence of the selected indices over the study period for each station. Negative/positive trends in the date of the first extreme occurrence indicate earlier/later onset of the hot extremes' season. Accordingly, negative/positive trends in the date of the last extreme indicate earlier/later ending of the hot extremes' season.

The results in Fig. 2 reveal an almost consistent pattern characterized by negative trends in the dates of the first and positive trends in the dates of the last hot extreme almost in all sites.

3.1.1. Timing of first hot extremes

Almost all sites experience statistically significant negative trends ($p < .05$) in the date of the first occurrence of one or more hot extremes indices, implying a statistically significant earlier beginning of the season of warm (or hot) weather (Fig. 2, lower panel). The magnitude of trend varies among different sites and indices. Larger trends are in general observed in the timing of nighttime (TNs) compared to daytime extremes at all sites. The rate of the earlier onset of TNs ranges between 3 and 4 days/decade (e.g. Iraklio, Larissa, Alexandroupolis, Methoni, Nicosia) but reaches much higher values, up to ~6 days/decade (e.g. Athens, Corfu, Kozani, Larnaca, Rhodes, Souda). Taking into consideration that the study periods span several decades, this suggests an earlier onset of TNs by approximately one month or more (depending on the site) since the mid 20th century in the study area. Statistically significant earlier shifts in the timing of hot nights ($T_{min} > 26$ °C) were also found in Athens and Nicosia (not shown). Apart from regional warming, this is possibly related to the progressive urbanization of the cities and the additive effect of the ongoing urban heat island (UHI) effect that maintains nighttime temperatures at high levels (Founda et al., 2015). Asymmetrical warming between maximum and minimum temperature in Cyprus with stronger warming rates in minimum temperature have been also reported in the past (Türkeş and Sariş, 2007).

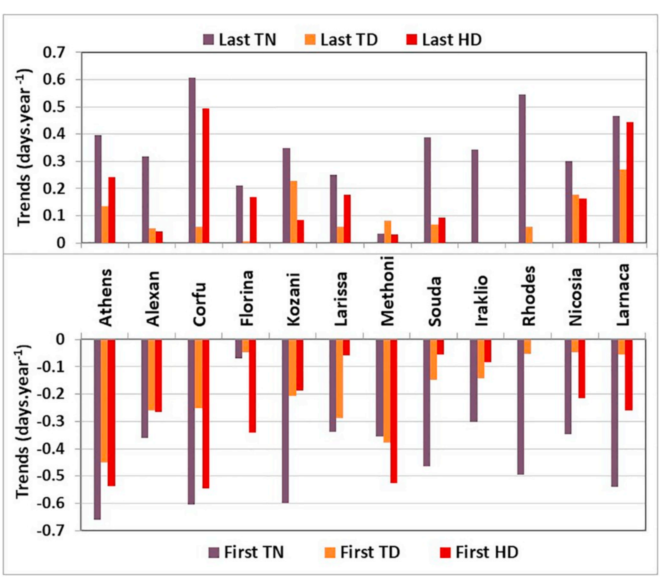

Fig. 2. Observed trends in the dates of first (low graph) and last (upper graph) hot extremes (TN, TD and HD) at the selected sites. (Athens trends refer to the sub-period 1976–2017).

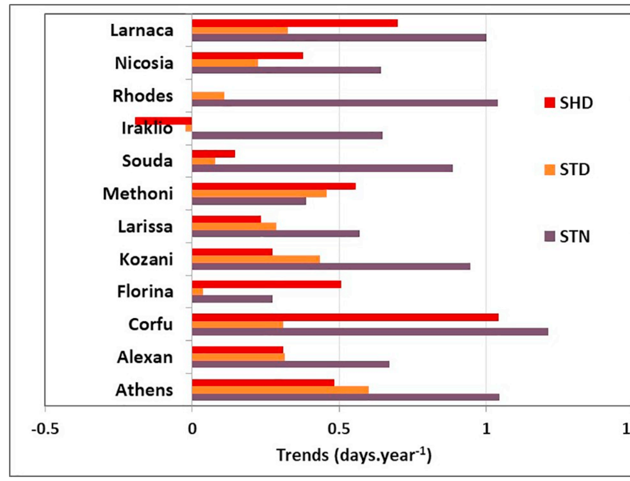

Fig. 3. Observed trends in the length of hot extremes' season (STN, STD and SHD) at the selected sites. (Athens trends refer to the sub-period 1976–2017.)

As regards the timing of daytime hot extremes, their trends are lower compared to nighttime ones, but still statistically significant at the majority of the stations. Negative trends (earlier shifts) in the timing of TDs or HDs are of the order of 2–3 days/decade. Stations of Western Greece (Methoni, Corfu) exhibit the highest earlier shifts in the occurrence of the first HD since the mid 20th century, with rates exceeding 5 days/decade. Similar rates are observed in Athens during the sub-period 1976–2017.

Athens has been experiencing an advancement of all hot extremes on centennial scale, as depicted from statistically significant negative trends in the long term. Nevertheless, the advancement of all hot extremes since the mid 1970s is outstanding, with accelerating rates varying approximately between 4 and 6 days/decade.

3.1.2. Timing of last hot extremes

Positive long-term trends in the dates of last hot extremes are observed at the selected sites, suggesting later ending of warm or hot weather (Fig. 2, upper graph). In general, the observed delays in the last hot extremes are less prominent compared to the earlier onset of the first hot extremes almost for all indices and sites. The maximum delays are observed in the occurrence of nighttime hot extremes. Statistically significant trends in the date of last TNs are observed at all sites, comparable with the trends in the date of first TNs.

Prominent positive trends in the dates of last hot night ($T_{min} > 26$ °C) are observed at urban areas, exceeding 10 days/decade since the mid 1970s in Athens and 17 days/decade in Nicosia (not shown).

With respect to daytime hot extremes, positive trends at almost all stations also suggest later occurrence in the year. Nevertheless, the trends are much smaller and not statistically significant for the majority

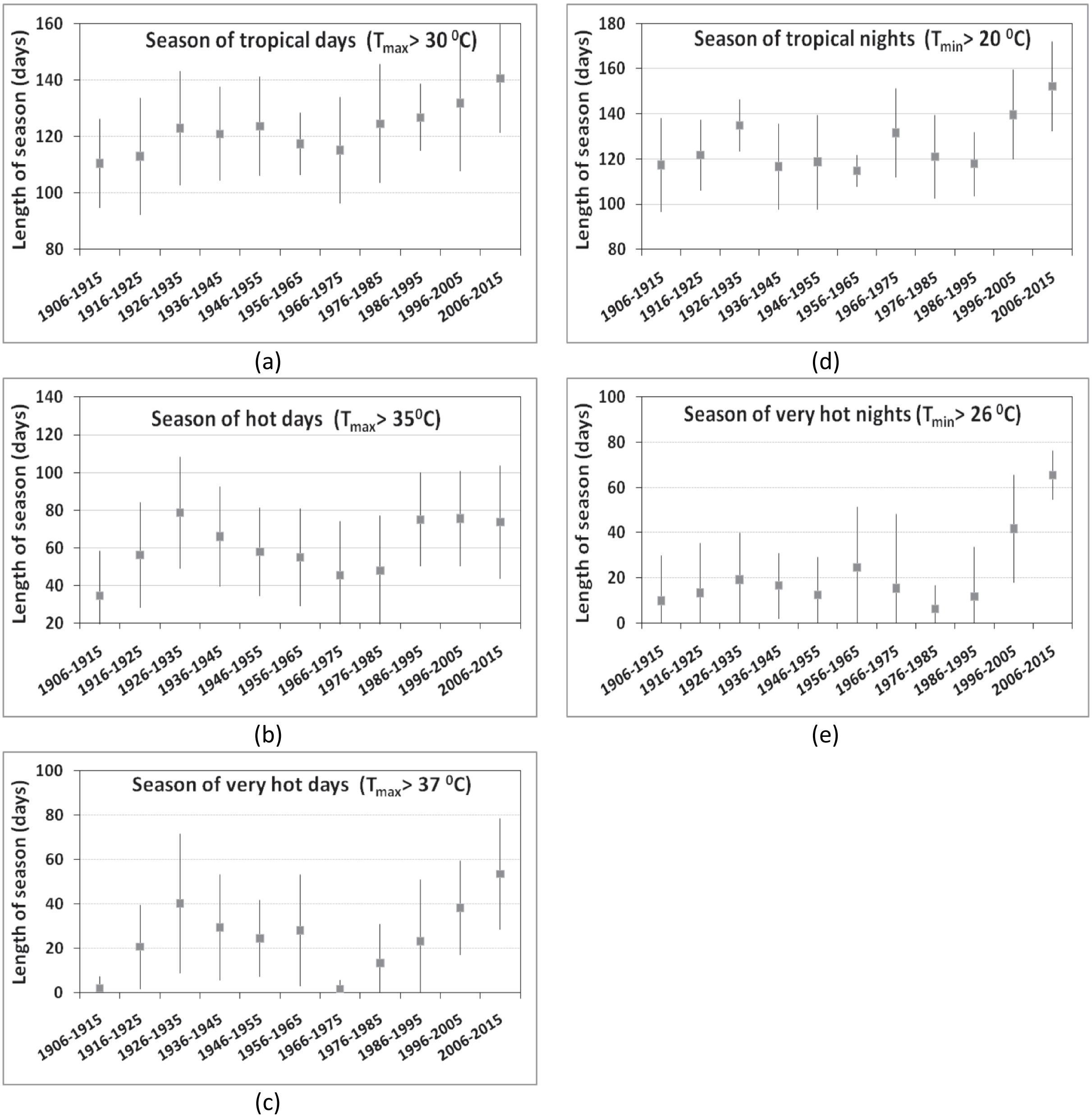

Fig. 4. (a–e): Long-term variation in the season's length of (a) tropical days (b) hot days (c) very hot days (d) tropical nights and (e) very hot nights in Athens, expressed as the average number of days per decade along with standard deviations (inter-annual variability within each decade).

of the stations, mainly regarding TDs. The trends in the occurrence of last HDs become significant in Athens, Corfu and Cyprus (Nicosia and Larnaca), while a strong trend in the occurrence of last very hot days was found in Athens since the mid 1970s. Coastal stations of southern Greece (Iraklio, Rhodes, Souda) reveal some common characteristics which are different from the general pattern observed at the rest of the stations. Although the stations present significant shifts (earlier or later) in the timing of TNs, analogous shifts in daytime extremes are very small or not statistically significant. It is possible that local circulations such as sea breezes and asymmetrical warming rates between land and sea play a dominant role, regulating timing and seasons of daytime hot extremes at coastal stations.

Although earlier start and later ending of hot extremes is found at almost all stations, the earlier onset is larger, implying an asymmetry between the beginning and the ending of the hot extremes' season. Similar asymmetrical patterns have been also reported in other studies concerning seasonal changes (e.g. Sparks and Menzel, 2002; Stine et al., 2009), or in Christidis et al. (2007) who found asymmetric increase in the growing season length largely due to the earlier onset of spring, rather than the later ending of autumn. Stine et al. (2009) concluded that observed differences in the warming rates between months over land actually reflect shifts in the timing of the seasons. We also estimated (not shown) that warming rates of late spring-early summer months (May–June) are more than twice as large as the rates in early autumn at most stations, except for coastal stations of southern Greece.

3.2. Observed trends in the season of hot extremes

The season of hot extremes was estimated from the number of days interceded between the first and last extreme in the year. Trends in the length of the extremes' season are depicted in Fig. 3. Positive trends suggest that all sites (except Iraklio) experience an expansion of the hot extremes' season for all indices, as a result of earlier and later shifts of their occurrence within the year. As stated previously, expansion is

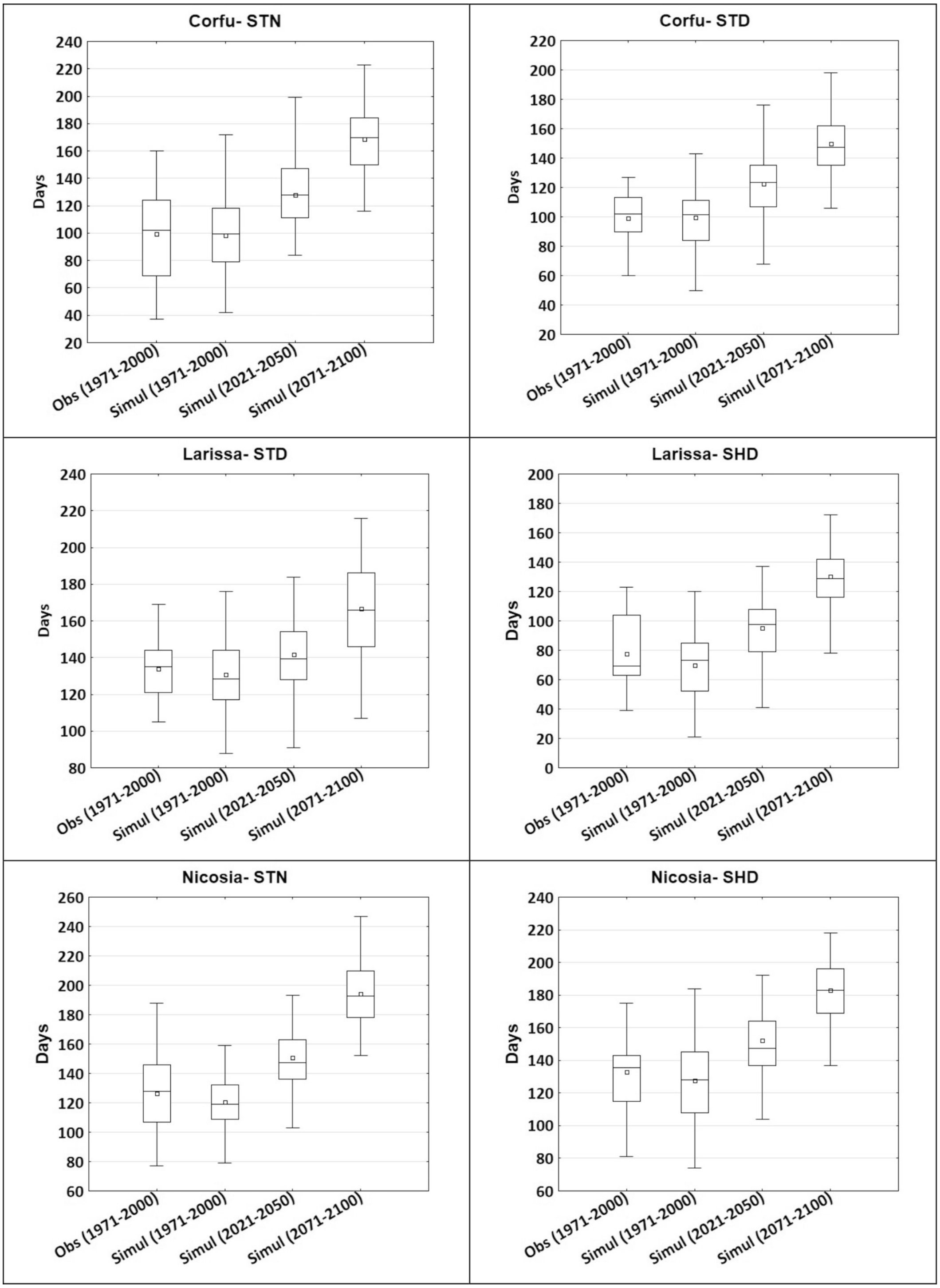

Fig. 5. Boxplots of hot extremes' season at selected sites (coastal, inland and urban) from observations (1971–2000) and simulations over the three periods 1971–2000, 2021–2050 and 2071–2100.

largely due to earlier onset of summer rather than delayed autumn. The trends in the season of TNs (STN) is statistically significant ($p < .05$) at all sites, with increasing rates being almost twice as large as the rates in daytime hot extremes. Prominent increases in the length of STN are observed in Athens, Corfu, Rhodes and Larnaca, with rates exceeding 10 days/decade. Western Greek stations like Corfu and Methoni experience also a large expansion in the season of HDs. Other stations experience a statistically significant increase in the season of at least one daytime hot extreme with the exception of the southern coastal stations in Crete (Iraklio and Souda), which experience significant lengthening only in the season of TNs.

The timing of the first and the last hot extreme in Athens was found to reveal a fluctuating pattern on centennial scale, with alteration of negative and positive trends, denoting different periods of lengthening and shrinkage of the season of extremes (Fig. 4). These periods follow closely the warm and cold periods of air temperature observed in Athens (Founda, 2011) but also across broader spatial scales, as for instance the cooler periods in the beginning of the 20th century and in the mid 1970s, and the warmer periods in the 1950s and from the mid 1970s onwards. An overwhelming increasing tendency of the season of

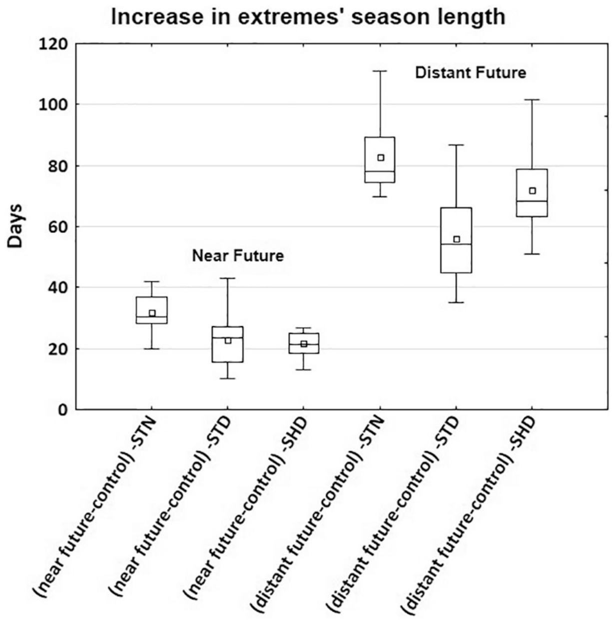

Fig. 6. Area averaged simulated anomalies in the length of STN, STD and SHD for the future periods 2021–2050 and 2071–2100 with respect to the control period 1971–2000, from the ensemble model. Area averaged values correspond to the mean of the land grids closest to the stations.

very hot nights ($T_{min} > 26$ °C) is observed during the last four decades, at a rate of 17 days/decade, while the increasing rate of the season of very hot days ($T_{max} > 37$ °C) is also profound in Athens, approximating 10 days/decade over the same period.

The overall long-term trends suggest a statistically significant ($p < .05$) lengthening of the season of all hot extremes on centennial scale.

3.3. Model evaluation and future simulations

Fig. 5 illustrates boxplots of the length of hot extremes' season over the past and future periods for selected coastal, inland and urban sites. The first two boxplots in each figure represent observed and simulated values for the control period 1971–2000, enabling also the evaluation of the regional climate models' performance against observations. The other two boxplots are produced from simulations for the periods 2021–2050 and 2071–2100, to represent the near and distant future climate respectively. Additional boxplots for other sites and indices are provided in Supplement along with the performance of individual models (Figs. S1–S3). The model performance was found to be sensitive to the selected index and site. Overall, the length of hot extremes' season was successfully captured by the ensemble model in most sites, with better performance in STD. Future simulations suggest prominent increases in the length of hot extremes' season in the near and distant future for all sites and indices (Figs. 5 & S1–S2). The length of STN and STD may exceed six months by the end of the century at some sites (e.g. Athens, Methoni, Nicosia). Yet, the length of SHD is projected to approximate 3–4 months in the distant future in most sites.

Fig. 6 depicts the area averaged simulated increase (anomaly) in the hot extremes' season for the future periods 2021–2050 and 2071–2100 with respect to the control period 1971–2000. Larger increases are simulated in the length of STN, which is projected to increase by one month in the near future and by more than two months in the distant future compared to the present climate (control period). The future lengthening in the STD and SHD is also very prominent. Specifically, projections under near future climate show an expansion of the season of TDs and HDs by about 20 days, while projections under distant future climate show a corresponding expansion by approximately two months compared to the present climate.

3.4. Simulated trends in the timing of extremes

We found marked increases in the length of hot extremes' season in the near and distant future, based on the climate models simulations. It is interesting to distinguish if and to what degree, the lengthening is due to earlier onset or extension of the season, or both. Fig. 7 illustrates simulated trends in the dates of first and last hot extreme from the three RCM realisations over the entire period of simulations, 1970–2100. All three RCM realisations indicate statistically significant negative trends in the date of first and positive trends in the date of last hot extreme, denoting both, an earlier beginning and a later ending of the hot extremes' season. The trends vary roughly between 2 and 6 days/decade, depending on model realisation, site and index. As regards TNs, negative and positive trends are of similar magnitude, indicating almost symmetrical changes in the beginning and ending of their season, which is also the case for most of the observed trends. With respect to TDs, negative trends are in general larger (in absolute values) compared to the positive trends, suggesting more pronounced earlier shifts at the beginning than later shifts at the ending of their season. These results are also in qualitative agreement with the observed trends (Fig. 2). However, simulated trends in the dates of last extremes are statistically significant and much higher compared to observations, suggesting an attenuation of asymmetrical changes in the future. This is also in agreement with the conclusions of Christidis et al. (2007) who found that future climate projections suggest that a later ending of autumn will also contribute significantly to the lengthening of the growing season. It should be noted though that the aforementioned simulated trends refer to the entire period 1970–2100, while the corresponding trends during the control period 1970–2000 were not found statistically significant in most cases.

Fig. 8 illustrates the observed (1896–2017) along with the simulated time series (1970–2100) from the three models of the dates of first and last TN, TD and HD for Athens. The total length of the study period including observations and simulations spans more than two centuries (1896–2100). The time series of first and last hot extreme diverge progressively over the years for all indices, but divergence is accelerating more after the mid 21st century, pointing to the outstanding future expansion of the hot extremes' season. Trends in first and last TNs are symmetrical and larger compared to TDs and HDs, with corresponding curves almost mirroring each other (Fig. 8a).

4. Discussion and conclusions

This study focuses on the Eastern Mediterranean, one of the most vulnerable areas to heat related risk globally. So far, evidence of climate change in the area has been largely manifested through strong warming rates and increased frequency of extremely hot weather. This study further explored possible significant shifts in the timing of different hot extreme indices and thus changes in their seasons' length based on historical climatic data at a number of stations in Greece and Cyprus, while future projections of seasonal changes were also estimated using data from several regional climate model realisations under the RCP 8.5 emissions scenario.

The analysis showed that a marked expansion of the hot extremes' season, through changes in their timing, is an additional major feature characterizing the area. Specifically, the analysis of observations at different sites pointed to a rather consistent general pattern characterized by a lengthening of the season of hot extremes at both sides. However, extensions at the beginning and end of the season are not always symmetrical, with most stations experiencing advancement rather than delayed ending of hot extremes. Changes in the seasonality of tropical nights was one of the most robust findings, with statistically significant earlier occurrence at the beginning and later occurrence at the ending of their season at all sites. The shifts at the beginning and

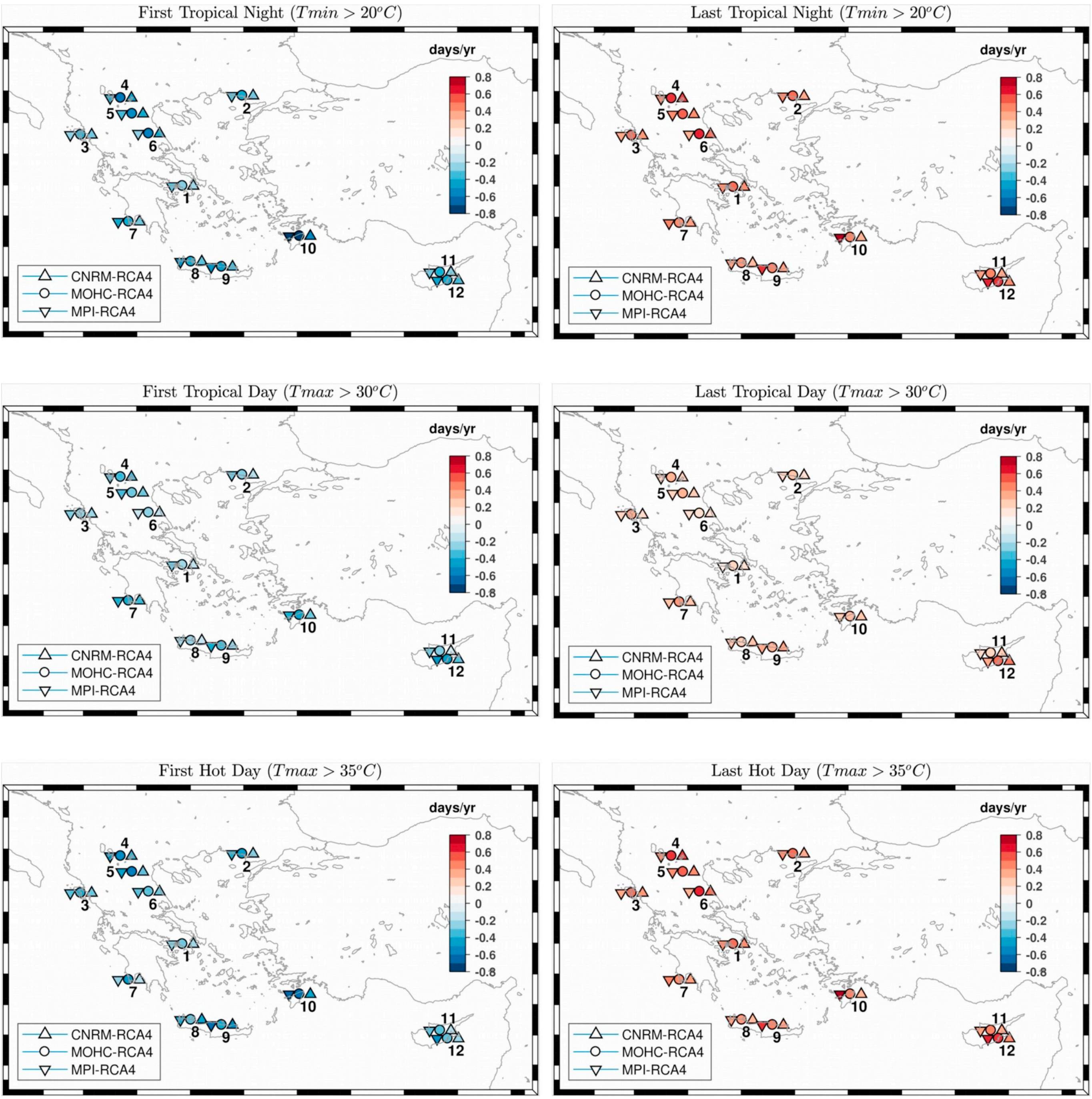

Fig. 7. Simulated trends in the first and last TN, TD and HD at the selected sites from the three models, CNRM-RCA4, MOHC-RCA4 and MPI- RCA4. Simulations cover the period 1970–2100. Negative trends in left panel indicate earlier occurrence of the first hot extreme and positive trends in right panel indicate later occurrence of the last hot extreme. All trends are statistically significant ($p < .05$).

ending are of comparable magnitude, contributing almost equally to the overwhelming lengthening of the season of tropical nights, which in some cases was found to exceed 10 days/decade since the mid 1970s.

Statistically significant increases in the length of the season of tropical and hot days were also observed at most sites, attributable largely to their earlier onset and to a lesser extent to extended ending. Coastal sites of southern Greece deviated from the general pattern, showing not statistically significant trends in the seasonality of daytime hot extremes. Local climate features such as sea breeze circulations seem to have a stronger impact on diurnal variability of air temperature at these sites.

The historical climatic records of NOA enabled the study of changes in timing and seasonality of hot extremes on centennial scale in Athens. Positive and negative anomalies in the length of the hot extremes' season were found to closely follow warming and cooling sub-periods. In addition to the (statistically significant) lengthening of the hot extremes' season in the long-term in Athens, it is stressed that the city has been experiencing a striking and persistent increase in the season of very hot days ($T_{max} > 37\,^{\circ}C$) and nights ($T_{min} > 26\,^{\circ}C$) since the mid 1970s, at rates of ~10 and 17 days/decade respectively. It is worth mentioning that during the past few years the city experienced a series of early heat waves (in 2007, 2010, 2016 and 2017), occurring for the first time during June (Founda and Giannakopoulos, 2009; Founda and Santamouris, 2017). Not only in Athens, but also in the other sites, the

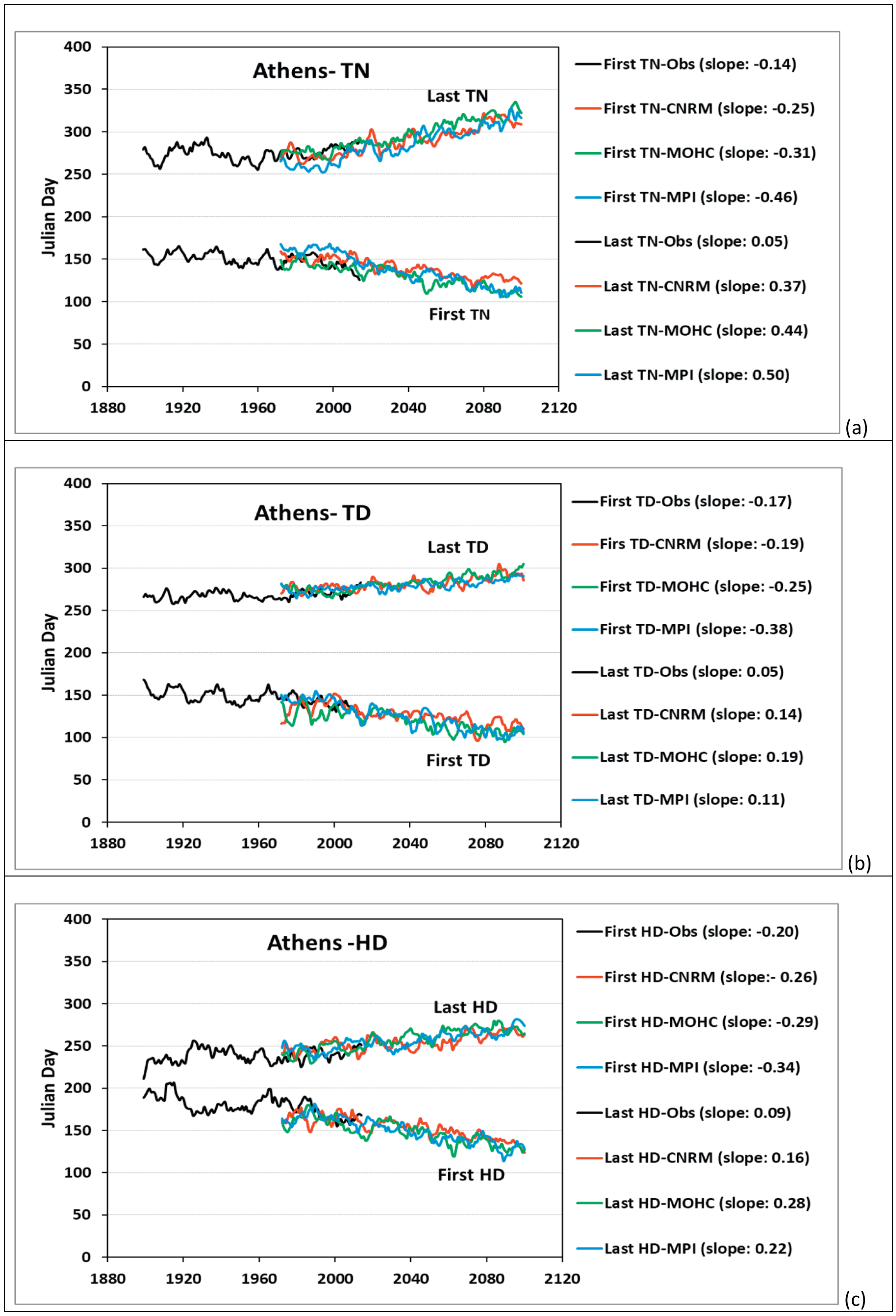

Fig. 8. Observed (1896–2017) along with simulated (1970–2100) trends in the first and last TN, TD and HD in Athens from the three models. Slopes of linear trends (days/year) are also depicted. All trends are statistically significant ($p < .05$). A 5-year moving average filter has been applied on the time series.

observed trends in timing of hot extremes were very sensitive to the length and especially to the beginning of the analyzed series. Higher trends were found from the mid 1970s onwards, following the observed persistent warming in the area since the mid 1970s.

As regards future projections, models suggest ongoing advancement of first and delays of last hot extremes at high rates and thus, a prominent further expansion of their season during the following decades. Area averaged simulations point to a marked lengthening of the hot extremes' season by approximately one month in the near future (2021–2050) and by two months or more by the end of the 21st century. Higher increases are projected for nighttime hot extremes.

The emerging signal in nighttime temperatures suggested by observations and simulations is not surprising, given the stronger impact of greenhouse effect on nighttime temperatures when the only source of energy comes from the atmosphere that re-emits infrared radiation. Additional factors such as increased cloudiness in the area could possibly link with differences between daytime and nighttime signal (Founda et al., 2017, 2018). Moreover, UHI effect constitutes an additional contributing factor for the observed changes in nighttime extremes at urban sites.

Our findings on the observed and projected expansion of the hot extremes' season in the Eastern Mediterranean are quite consistent with recent research examining the variability of hot extremes in terms of underlying physical mechanisms and specifically of the role of land-atmosphere coupling and the importance of soil moisture-temperature feedbacks on summer climate variability (Seneviratne et al., 2006, 2010; Vautard et al., 2007; Zampieri et al., 2009). Increasing drought conditions are also reported in the study area, mostly manifested

through decline in precipitation frequency, (Zerefos et al., 2011; Founda et al., 2013), but also declines in soil moisture and evapotranspiration pointing to linkages between drying and heating (Diffenbaugh et al., 2007; Orlowsky and Seneviratne, 2012).

Implications of changes in the hot extremes' season are numerous and multidisciplinary. Seasonal shifts can have both negative and positive effects on many sectors such as the environment, economy and health. For instance, onset of warm weather signifies also the onset of the touristic period, especially at coastal touristic destinations. Lengthening of the touristic period has a positive effect on local economies. However, lengthening of the season of hot weather has a strong negative impact on the energy sector by increasing cooling demand. Yet, elongation of the hot extremes' season could further stress environment by increasing fire risk period (Barbero et al., 2015). Furthermore, population exposure and vulnerability to hot weather is strongly affected by the timing of hot extremes and duration of their season. It becomes clear that the changes in the season of hot extremes and particularly the advancing of hot days and heat waves should be taken very seriously into consideration by authorities in order to prepare adaptation plans against thermal risk and for a longer period than experienced in the past. Combined with socioeconomic information on exposure, the outcome of this study can serve as a scientific basis for assessment of heat related risk in the area, the discussion of adaptation measures, and vulnerability considerations.

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Data availability

Observational data for Athens and simulated data are available by the authors upon request. To access observational data for other stations in Greece and Cyprus, contact Hellenic National Meteorological Service ((https://www.hnms.gr) and the Cyprus Department of Meteorology (http://www.moa.gov.cy/moa/ms/ms.nsf/DMLforecast_en/DMLforecast_en#).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloplacha.2019.02.012.

References

Abatzoglou, J.T., Barbero, R., 2014. Observed and projected changes in absolute temperature records across the contiguous United States. Geophys. Res. Lett. (18), 41. https://doi.org/10.1002/2014GL061441.

Alexander, L.V., Zhang, X., Peterson, T.C., Caesa, J., Gleason, B., et al., 2006. Global observed changes in daily climate extremes of temperature and precipitation. J. Geophys. Res. Atmos. 111, D05109. https://doi.org/10.1029/2005jd006290.

Anderson, G.B., Bell, M.L., 2011. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. Environ. Health Perspect. 119 (2), 210–218. https://doi.org/10.1289/ehp.1002313.

Barbero, R., Abatzoglou, J.T., Larkin, N.K., Kolden, C.A., Stocks, B., 2015. Climate change presents increased potential for very large fires in the contiguous United States. Int. J. Wildland Fire 24 (7), 892–899. https://doi.org/10.1071/WF15083.

Chen, Y., Li, Y., 2017. An inter-comparison of three heat wave types in China during 1961–2010: observed basic features and linear trends. Sci. Rep. 7, 45619. https://doi.org/10.1038/srep45619.

Chen, T., Sarnat, S.E., Grundstein, A.J., Winquist, A., Chang, H.H., 2017. Time-series analysis of heat waves and emergency department visits in Atlanta, 1993 to 2012. Environ. Health Perspect. 125 (5), 057009. https://doi.org/10.1289/EHP44.

Christidis, N., Stott, P.A., Brown, S., Karoly, D.J., Caesar, J., 2007. Human contribution to the lengthening of the growing season during 1950–99. J. Clim. 20, 5441–5454. https://doi.org/10.1175/2007JCLI1568.1.

Collins, D.A., Della-Marta, P.M., Plummer, N., Trewin, B.C., 2000. Trends in annual frequencies of extreme temperature events in Australia. Aust. Meteorol. Mag. 49, 277–292.

Collins, W.J., Bellouin, N., Doutriaux-Boucher, M., Gedney, N., Halloran, P., Hinton, T., Woodward, S., 2011. Development and evaluation of an Earth-System model – HadGEM2. Geosci. Model Dev. 4 (4), 1051–1075. https://doi.org/10.5194/gmd-4-1051-2011.

Coumou, D., Robinson, A., 2013. Historic and future increase in the global land area affected by monthly heat extremes. Environ. Res. Lett. 8, 034018. https://doi.org/10.1088/1748-9326/8/3/034018.

Coumou, D., Robinson, A., Rahmstorf, S., 2013. Global increase in record-breaking monthly-mean temperatures. Clim. Chang. 118, 771–782. https://doi.org/10.1007/s10584-012-0668-1.

Della-Marta, P.M., Haylock, M.R., Luterbacher, J., Wanner, H., 2007. Doubled length of Western European summer heat waves since 1880. J. Geophys. Res. Atmos. 112 (D15103). https://doi.org/10.1029/2007JD008510.

Déqué, M., 2007. Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: model results and statistical correction according to observed values. Glob. Planet. Chang. 57, 16–26. https://doi.org/10.1016/j.gloplacha.2006.11.030.

Diffenbaugh, N.S., Pal, J.S., Giorgi, F., Gao, X., 2007. Heat stress intensification in the Mediterranean climate change hotspot. Geophys. Res. Lett. 34, L11706. https://doi.org/10.1029/2007GL030000.

Fischer, E.M., Knutti, R., 2015. Anthropogenic contribution to global occurrence of heavy-precipitation and high-temperature extremes. Nat. Clim. Chan. 5, 560–564. https://doi.org/10.1038/nclimate2617.

Fischer, E.M., Schär, C., 2010. Consistent geographical patterns of changes in high-impact European heatwaves. Nat. Geosci. 3, 398–403.

Fontana, G., Toreti, A., Ceglar, A., De Sanctis, G., 2015. Early heat waves over Italy and their impacts on durum wheat yields. Nat. Hazards Earth Syst. Sci. 15, 1631–1637. https://doi.org/10.5194/nhess-15-1631-2015.

Founda, D., 2011. Evolution of the air temperature in Athens and evidence of climatic change – a review. Adv. Build. Energy Res. (ABER) 5, 7–41. https://doi.org/10.1080/17512549.2011.582338.

Founda, D., Giannakopoulos, C., 2009. The exceptionally hot summer of 2007 in Athens, Greece – a typical summer in the future climate? Glob. Planet. Chang. 67, 227–236. https://doi.org/10.1016/j.gloplacha.2009.03.013.

Founda, D., Santamouris, M., 2017. Synergies between Urban Heat Island and Heat Waves in Athens (Greece) during an extremely hot summer (2012). Sci. Rep. 7, 10973. https://doi.org/10.1038/s41598-017-11407-6.

Founda, D., Papadopoulos, K.H., Petrakis, M., Giannakopoulos, C., Good, P., 2004. Analysis of mean, maximum and minimum temperature in Athens from 1897–2001 with emphasis on the last decade: trends, warm events, and cold events. Glob. Planet. Chang. 44, 27–38. https://doi.org/10.1016/j.gloplacha.2004.06.003.

Founda, D., Giannakopoulos, C., Pierros, F., Kalimeris, A., Petrakis, M., 2013. Observed and projected precipitation variability in Athens over a 2.5 Century Period. Atmos. Sci. Lett. 14, 72–78. https://doi.org/10.1002/asl2.419-2013.

Founda, D., Pierros, F., Petrakis, M., Zerefos, C., 2015. Inter-decadal variations and trends of the Urban Heat Island in Athens (Greece) and its response to heat waves. Atmos. Res. 161–162, 1–13. https://doi.org/10.1016/j.atmosres.2015.03.016.

Founda, D., Pierros, F., Sarantopoulos, A., 2017. In: Karacostas, T.S. (Ed.), Evidence of Dimming/Brightening over Greece from Long-Term Observations of Sunshine Duration and Cloud Cover. Perspectives on Atmospheric Sciences. Springer International Publishing, Switzerland, pp. 753–759. https://doi.org/10.1007/978-3-319-350950_108.

Founda, D., Nastos, P.T., Pierros, F., Kalimeris, A., 2018. Historical observations of cloudiness (1882–2012) over a large urban area of the eastern Mediterranean (Athens). Theor. Appl. Climatol. https://doi.org/10.1007/s00704-018-2596-0.

Guerreiro, S.B., Dawson, R.J., Kilsby, C., Lewis, E., Ford, A., 2018. Future heat waves, droughts and floods in 571 European cities. Environ. Res. Lett. 13, 034009. https://doi.org/10.1088/1748-9326/aaaad3.

Habeeb, D., Vargo, J., Stone, B., 2015. Rising heat wave trends in large US cities. Nat. Hazards 76, 1651–1665. https://doi.org/10.1007/s11069-014-1563-z.

Hajat, S., Kovats, R.S., Atkinson, R.W., Haines, A., 2002. Impact of hot temperatures on death in London: a time series approach. J. Epidemiol. Community Health 56, 367–372.

Hempel, S., Frieler, K., Warszawski, L., Schewe, J., Piontek, F., 2013. A trend-preserving bias correction – the ISI-MIP approach. Earth Syst. Dynam. 4, 219–236. https://doi.org/10.5194/esd-4-219-2013.

IPCC, 2014. In: Core writing Team, Pachauri, R.K., Meyer, L.A. (Eds.), Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland Available at. http://ar5-syr.ipcc.ch/, Accessed date: 11 December 2018.

Kalkstein, L.S., Greene, J.S., Mills, D.M., Perrin, A.D., Samenow, J.P., Cohen, J.C., 2008. Analog European Heat Waves for U.S. cities to analyze impacts on heat-related mortality. BAMS Jan 2008, 75–85. https://doi.org/10.1175/BAMS-89-1-75.

Klein Tank, A.M.G., Konnen, G.P., 2003. Trends in indices of daily temperature and precipitation extremes in Europe, 1946–1999. J. Clim. 16, 3665–3680. https://doi.org/10.1175/1520-0442(2003)016<3665:TIIODT>2.0.CO;2.

Kuglitsch, F.G., Toreti, A., Xoplaki, E., Della Marta, P.M., Zerefos, C.S., Türkeş, M., Luterbacher, J., 2010. Heat wave changes in the eastern Mediterranean since 1960. Geophys. Res. Lett. 37, L04802. https://doi.org/10.1029/2009GL041841.

Kyselý, J., 2004. Mortality and displaced mortality during heat waves in the Czech

Republic. Int. J. Biometeorol. 49, 91–97. https://doi.org/10.1007/s00484-004-0218-2.

Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., Chenoweth, J., El Maayar, M., et al., 2012. Climate change and impacts in the eastern Mediterranean and the Middle East. Clim. Chang. 114 (3), 667–687. https://doi.org/10.1007/s10584-012-0418-4.

Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., et al., 2014. Model projected heat extremes and air pollution in the eastern Mediterranean and Middle East in the twenty-first century. Reg. Environ. Chang. 14 (1937). https://doi.org/10.1007/s10113-013-0444-4.

Meehl, G.A., Tebaldi, C., 2004. More intense, more frequent, and longer lasting heat waves in the 21st century. Science 305 (5686), 994–997. https://doi.org/10.1126/science.1098704. 15310900.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., et al., 2007. Global climate projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B. (Eds.), Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge, UK Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Nastos, P.T., Matzarakis, A., 2008. Variability of tropical days over Greece within the second half of the twentieth century. Theor. Appl. Climatol. 93, 75–89. https://doi.org/10.1007/s00704-007-0325-1.

Nastos, P.T., Philandras, C.M., Founda, D., Zerefos, C.S., 2011. Air temperature trends related to changes in atmospheric circulation in the wider area of Greece. Int. J. Remote Sens. 32 (3), 737–750. https://doi.org/10.1080/01431161.2010.517796.

Orlowsky, B., Seneviratne, S.I., 2012. Global changes in extreme events: regional and seasonal dimension. Clim. Chang. 110, 669–696. https://doi.org/10.1007/s10584-011-0122-9.

Panda, D.K., Mishra, A., Kumar, A., Mandal, K.G., Thakur, A.K., Srivastava, R.C., 2014. Spatiotemporal patterns in the mean and extreme temperature indices of India, 1971–2005. Int. J. Climatol. 34, 3585–3603. https://doi.org/10.1002/joc.3931.

Perkins, S.E., Alexander, L.V., Nairn, J.R., 2012. Increasing frequency, intensity and duration of observed global heat waves and warm spells. Geophys. Res. Lett. 39, L20714. https://doi.org/10.1029/2012GL053361.

Perkins-Kirkpatrick, S.E., Gibson, P.B., 2017. Changes in regional heat wave characteristics as a function of increasing global temperature. Sci. Rep. 7, 12256. https://doi.org/10.1038/s41598-017-12520-2.

Popke, D., Stevens, B., Voice, A., 2013. Climate and climate change in a radiative-convective equilibrium version of ECHAM6. J. Adv. Model. Earth Syst. 5 (1), 1–14. https://doi.org/10.1029/2012MS000191.

Post, E., Steinman, B.A., Mann, M.E., 2018. Acceleration of phenological advance and warming with latitude over the past century. Sci. Rep. 8, 3927. https://doi.org/10.1038/s41598-018-22258-0.

Poumadère, M., Mays, C., Le Mer, S., Blong, R., 2005. The 2003 heat wave in France: dangerous climate change here and now. Risk Anal. 25, 1483–1494. https://doi.org/10.1111/j.1539-6924.2005.00694.x.

Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N., Rafaj, P., 2011. RCP8.5-a scenario of comparatively high greenhouse gas emissions. Clim. Chang. 109 (33). https://doi.org/10.1007/s10584-011-0149-y.

Scherrer, S.C., Fischer, E.M., Posselt, R., Liniger, M.A., Croci-Maspoli, M., Knutti, R., 2016. Emerging trends in heavy precipitation and hot temperature extremes in Switzerland. J. Geophys. Res. Atmos. 121, 2626–2637. https://doi.org/10.1002/2015JD024634.

Schwartz, M., Ahas, R., Aasa, A., 2006. Onset of spring starting earlier across the Northern Hemisphere. Glob. Chang. Biol. 12, 343–351. https://doi.org/10.1111/j.1365-2486.2005.01097.x.

Seneviratne, S.I., Lüthi, D., Litschi, M., Schär, C., 2006. Land-atmosphere coupling and climate change in Europe. Nature 443, 205–209. https://doi.org/10.1038/nature05095.

Seneviratne, S.I., Corti, T., Davin, E.L., Hirschi, M., Jaeger, E.B., Lehner, I., Orlowsky, B., Teuling, A., 2010. Investigating soil moisture-climate interactions in a changing climate: a review. Earth Sci. Rev. 99, 125–161. https://doi.org/10.1016/j.earscirev.2010.02.004.

Sparks, T., Menzel, A., 2002. Observed changes in seasons: an overview. Int. J. Climatol. 22, 1715–1725. https://doi.org/10.1002/joc.821.

Stine, A.R., Huybers, P., Fung, I.Y., 2009. Changes in the phase of the annual cycle of surface temperature. Nature 457, 435–440. https://doi.org/10.1038/nature07675.

Stott, P.A., Christidis, N., Otto, F.E.L., Sun, Y., Vanderlinden, J.-P., van Oldenborgh, G.J., Vautard, R., von Storch, H., Walton, P., Yiou, P., Zwiers, F.W., 2016. Attribution of extreme weather and climate-related events. WIREs Clim. Change 7, 23–41. https://doi.org/10.1002/wcc.380.

Strandberg, G., Bärring, A., Hansson, U., et al., 2014. CORDEX scenarios for Europe from the Rossby Centre regional climate model RCA4. In: Swedish Meteorological and Hydrological Institute (SMHI) Report Meteorology and Climatology No 116, (ISSN: 0347-2116).

Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A.J., Li, F., Chen, H., 2010. The urban heat island and its impact on heat waves and human health in Shanghai. Int. J. Biometeorol. 54, 75–84. https://doi.org/10.1007/s00484-009-0256-x.

Tong, S., Wang, X.Y., Yu, W., et al., 2014. The impact of heatwaves on mortality in Australia: a multicity study. BMJ Open 4, e003579. https://doi.org/10.1136/bmjopen-2013-003579.

Türkeş, M., Sariş, F., 2007. Trends and changes of mean, maximum, minimum temperature and precipitation series in Northern Cyprus. North. J. Black Sea Mediterr. Environ. 13, 281–304.

Vautard, R., Yiou, P., D'Andrea, F., de Noblet, N., Viovy, N., Cassou, C., Polcher, J., Ciais, P., Kageyama, M., Fan, Y., 2007. Summertime European heat and drought waves induced by wintertime Mediterranean rainfall deficit. Geophys. Res. Lett. 34, L07711. https://doi.org/10.1029/2006GL028001.

Voldoire, A., Sanchez-Gomez, E., Salas y Mélia, D., Decharme, B., Cassou, C., Sénési, S., Chauvin, F., 2012. The CNRM-CM5.1 global climate model: description and basic evaluation. Clim. Dyn. 40 (9), 2091–2121. https://doi.org/10.1007/s00382-011-1259-y.

Zampieri, M., D'Andrea, F., Vautard, R., Ciais, P., de Noblet-Ducoudré, N., Yiou, P., 2009. Hot European summers and the role of soil moisture in the propagation of Mediterranean drought. J. Clim. 22, 4747–4758. https://doi.org/10.1175/2009JCLI2568.1.

Zerefos, C., Repapis, C., Giannakopoulos, C., Kapsomenakis, J., et al., June 2011. The Climate of the Eastern Mediterranean the Climate of the Eastern Mediterranean and Greece: Past, Present and Future the Environmental, Economic and Social Impacts of Climate Change in Greece. Bank of Greece978-960-7032-58-4.

Zhang, X., Alexander, L.V., Hegerl, G.C., Jones, P., Klein Tank, A., Peterson, T.C., Trewin, B., Zwiers, F.W., 2011. Indices for monitoring changes in extremes based on daily temperature and precipitation data. WIREs Clim. Chang. 2 (6), 851–870. https://doi.org/10.1002/wcc.147.